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Optimization of Hard Disk Drive Heads Cleaning by Using Ultrasonics and Prevention of Its Damage

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Abstract

This paper investigates the optimization of hard disk drive heads under various experimental conditions such as ultrasonic frequency, sonication time, ultrasonic power and cleaning solvent. The ranges of frequency and ultrasonic power studied were 40 – 132 kHz and 100 – 500W respectively. Three solvents were tested to compare the cleaning efficiency and parts damage (low boiling point solvent: acetone and high boiling point solvent: N- Methyl Pyrolidone (NMP) around 200 ^{o}C and mixture of acetone 30% and NMP 70%). The best cleaning condition obtained from the experiments are 40 kHz with 5min followed by 58 kHz 5min followed by 132 kHz with 4min followed by 58/132 kHz with 4 min. The removal efficiency (85%) is high for multiple frequencies with shorter cleaning time of each frequency compared to single frequency (70%) with longer cleaning time of same frequency (58 kHz). The surface damage induced by Ultrasonics at the contact area is almost 0 for the best cleaning condition irrespective of the solvent used (~0.01% for acetone). As the power level increases, damage of parts also increases. The cavitation intensity is higher for higher power level. Therefore, the parts undergo more vibration and leads to more parts damage. The parts damage is more for acetone as compared to NMP. The result also indicates that the removal efficiency is high for Co-solvent (acetone +NMP) comapred to acetone or NMP alone. The AlTiC surface profile of the burned parts can be measured by using Atomic Force Microscope technique (AFM). The result indicates that the surface roughness value (Ra) obtained from AFM analysis for good and burned slider was 2.294 nm and 8.288 nm respectively. The Ra value was almost 4 times higher for burned slider. The defects/contamination on the AlTiC surface can be detected by using Energy Dispersive X-Ray (EDX) analysis.

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1. Introduction

Slider is an important sensitive component of hard disk drive which is responsible for translating digital information to analog (electrical) pulse during WRITE function and translating analog to digital information during READ function. The Air Bearing Surface (ABS) view of slider is as shown in Fig.1. The slider body consists of many material stacks and it is easily damaged by vibration and other means.

Ultrasonic cleaning systems, under certain conditions, have the potential to damage components being cleaned when the material of construction is sensitive to ultrasonic cavitational attack, or when the material itself is prone to vibrational damage. As parts are cleaned, they rest perfectly stationary in the tank, and are attacked more aggressively by the ultrasonic cleaning system at the standing wave locations. As a result, microscopic erosion of the surface occurs. When ultrasound is applied to a medium such as water, two principal flow mechanisms are introduced—cavitational, and acoustic streaming. Cavitation is said to occur whenever the vapor pressure at any point in a liquid drops below the vapor pressure of the liquid. Such low pressure zones can be produced by a local increase in velocity (in accordance with Bernoulli's equation) as in eddies or vortices, or over boundary contours, or by rapid vibration of the boundary [Nagarajan et al., 2006]. Collapse of these cavities in high pressure zones can cause extensive erosion or pitting of substrates in the regions of bubble collapse [Nagarajan et al., 2006 and John Fuchs., 2002]. Cavitation erosion of surfaces is a physical phenomenon. While low gas content increases the cavitation threshold pressure, it will also increase cavitation damage since those cavities that do form collapse more violently in the absence of cushioning gas [Flyn et al., 1966].

Cleaning at typical ultrasonic frequencies (40-100 kHz, used for less critical parts in other industries) became somewhat discredited in semiconductor manufacturing, since associated cavitation implosion can cause surface damage (Halbert., 1988). However, it was later found by engineers at RCA that sonic cleaning in the 0.8 to 0.9 MHz range (termed "megasonic" cleaning), was effective at removing surface contaminants without inflicting damage [Roman., 1997]. The investigators concluded that at megasonic frequencies there was insufficient time between wave passages for the formation and implosion of cavities to occur. Cavitation-induced erosion of metal surfaces has previously been reported by Boudjouk. It was postulated by Komfeld and Suvorov, and experimentally verified by Naude and Ellis. The energy release is greater for higher ultrasonic intensities, lower ultrasonic frequencies, and higher surface tension at the bubble-liquid interface. Apart from ultrasonic frequency and intensity, tank size, transducer location, temperature, choice of liquid medium, basket design, part orientation, and undulation (movement of parts during cleaning) all have an effect on ultrasonic cleaning efficiency as well as parts damage [Komfeld et al., 1944].

In the following sections, contamination removal from head, damage of head and prevention of hard disk drive heads under various experimental conditions such as ultrasonic frequency, sonication time, ultrasonic power and cleaning solvents were discussed.

2. Experimental Details

In this study an enclosed ultrasonic bath-type tank equipped with bottom mounted transducers was used. The tank was operated with different frequency range 40 – 132 kHz, and power levels 100 – 500W. In dual-frequency mode, total power input to drive the two sets of transducers is 1000W. The enclosed ultrasonic tank can be operated at different solvent mode and temperature. To study the effect of cleaning, the slider bar was placed in a vertical tray as shown in Fig. 2 and then the tray was moved to ultrasonic tank filled with solvent. The main contaminants present in the slider bar was separated into three categories i.e. particles, adhesives and chemical residues. The total contamination and defects present on the slider bar was characterized by 100x microscope inspection for each test. The 100x microscope inspection was done before and after the experiments. The total number of slider bar taken for the experiment was 5 bars per run. For any particular operating condition, three experiments were run, three removal efficiency values were measured, and their average was calculated.

The experiment was carried out for three different types of solvent mode i.e. low boiling point solvent (acetone), high boiling point solvent (NMP) and Co-solvent (30% acetone + 70% NMP). Two different types of parts holding fixtures were studied to understand the parts damage. The tray used to hold the bar during ultrasonic cleaning is shown in Fig.2. A slider bar consists of total 54 sliders. The fixture used to hold the slider during U/S cleaning is different from bar cleaning fixture. But the tray/fixture material used to hold the parts are same. The after-clean sliders were inspected by the same operator who did the before-clean inspection and the percent removal efficiency was calculated. The uncertainty in the measured experimental data is +/- 3%. The defective parts are further analyzed by using AFM technique.

Fig. 2 Tray used to hold bars during U/S cleaning

The percent removal efficiency, η (%), can be defined as follows:

$$\eta = \left[\frac{N_{cb} - N_{ca}}{N_{cb}} \right] \times 100 \tag{1}$$

where, N_{cb} is the number of contaminated sliders before cleaning and N_{ca} is the number of contaminated sliders after sonic cleaning.

Fig. 1. ABS view of slider body

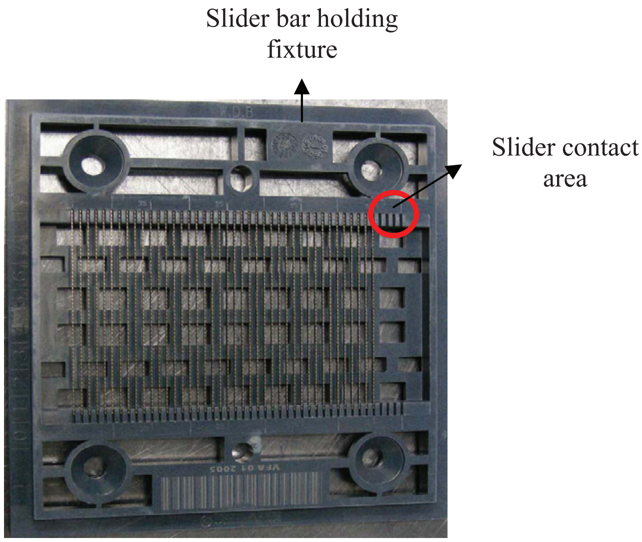

Fig. 2. Tray used to hold bars during U/S cleaning

3. Results and Discussion

3.1. Mechanism of cleaning and parts damage

When an acoustic wave propagates through a liquid containing microscopic gas inclusions, these "nucleation sites" can be mechanically activated, at which point they spawn free bubbles which then undergo highly energetic volume pulsations. Associated with these pulsations is a broad range of linear and nonlinear mechanical behaviour, the nature of which will primarily depend on the acoustic pressure amplitude and the equilibrium bubble. This activity, which is termed acoustic cavitation, is often accompanied with other physical (erosion, unpassivation and emulsification) or chemical (the production of radical and excited species; single electron transfer) interactions.

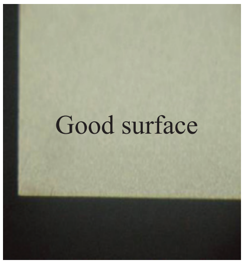

Fig. 3. Comparison of good and defective AlTiC surface after experiment

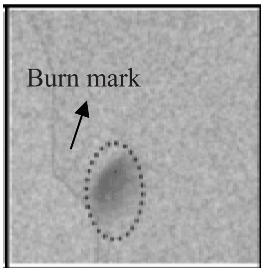

Fig. 4. Defects/ burn mark in AlTiC surface after cleaning

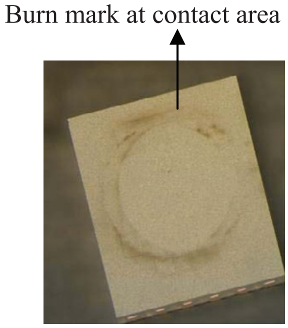

Fig. 5. SEM view of AlTiC surface

The good and defective AlTiC surfaces (Fig.5) after experiments are shown in Fig. 3 and 4. The burn mark/erosion part is also called as darkening or oxidation of the metal surface. When the bubble collapses, a powerful shock wave is produced, this impinges on substrate held immersed in the solvent and causes parts cleaning as well as damage. The experimental data indicates that the parts damage is more at the contact area between the AlTiC surface of the bar and tray used to hold parts [Fig. 3 and 4]. This is due to the fact that the stress amplitude is maximum at the fluid-solid interface because of reflection of the waves. This reflection of the waves causes more damage at fluid solid interface. Cavitation erosion is said to occur when the substrate suffers serious pitting or other loss of material (Nagarajan et al).

From Fig. 4, it can be seen that the defective area takes the shape of the tray (contact area of tray/AlTiC surface) used to hold the parts during cleaning. When ultrasonic cleaning the cavitation bubble strikes the surface of a part, neighbouring liquid is blasted away from the part in a direction which is dependent upon the angle between the ultrasonic cavitation, and the surface of the part. If the cavitation produced is perfectly perpendicular to the surface of the part, the neighbouring liquid is displaced evenly around the central strike location, thereby producing a circular spot of erosion [Fig. 4]. This is mainly due to vibrational action of parts used for cleaning. In most cases, cavitational action is not perfectly perpendicular to the surface of the parts. As such, neighboring fluid tends to be displaced in a specific direction, which yields the comet-like appearance [Fig. 3]. Some components, such as those manufactured of highly-polished aluminum, can quickly be damaged by ultrasonic cleaning action due to cavitational erosion of the parts, a condition where the ultrasonic scrubbing action actually erodes the surfaces of the parts [Nagarajan et al., 2007]. When these parts are cleaned in a standard ultrasonic cleaner, the surface of the parts appears mottled, and covered with a pattern of small comet-like spots. These "comets" are created when the ultrasonic activity essentially drills holes in the surface of the objects being cleaned. The head of the comet is the location of most intense ultrasonic activity, while the tail of the comet represents the direction that the fluid was blasted away during the cleaning action. The distance between neighboring "comets" and the degree of damage produced will be dependent upon the ultrasonic frequency in use.

High-energy mechanical vibrations can very easily be converted to heat, either by friction at interfaces between different parts or by damping ("internal friction") within the materials. One consequence of the immense accelerations generated by high-power ultrasonics is that unless surfaces are held very firmly together they will tend to separate. Where one surface is required to move over another with minimum friction, this effect can be exploited - while there is no contact between the surfaces friction is reduced to zero. Furthermore the relative movement may cease during the time when the surfaces are in contact, allowing all movement to happen under zero friction while they are apart. This is one of the effects used for ultrasonic metal forming - the tools vibrate so that the workpiece can move over them with little or no friction. Damage can be produced after only a few minutes of ultrasonic cleaning, depending upon the sensitivity of the parts being cleaned, cleaning agents in use, and operational ultrasonic frequency and operational power. These topics will be discussed in following sections.

3.1.1. AFM analysis

The defective parts were submitted for AFM analysis to see the AlTiC surface profile roughness of darkening area and good area. The surface profile measured by using AFM technique for burn and no burn surface is shown in Fig. 3 and 4. The surface roughness (Ra) value obtained from AFM analysis for good surface and burned surface is 2.294 nm and 8.288 nm respectively. The Ra value is almost 4 times higher for burned AlTiC surface.

Where, Ra is the arithmetic average of the roughness profile. The roughness value of burned surface has changed significantly due to material removal/oxidation of the Al_2O_3 surface. It indicates that the Al_2O_3 surface is very sensitive to damage.

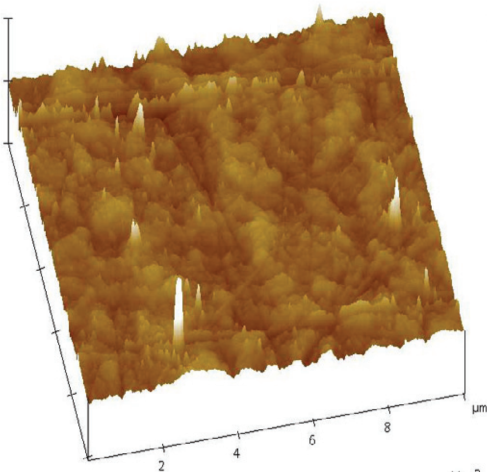

Fig. 6a. AFM image for good AlTiC surface

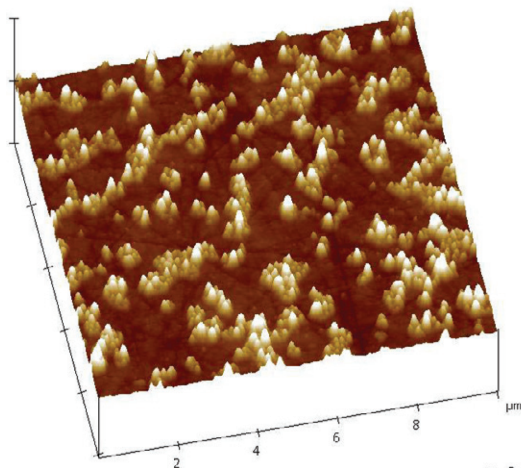

Fig. 6b. AFM image for burned AlTiC surface

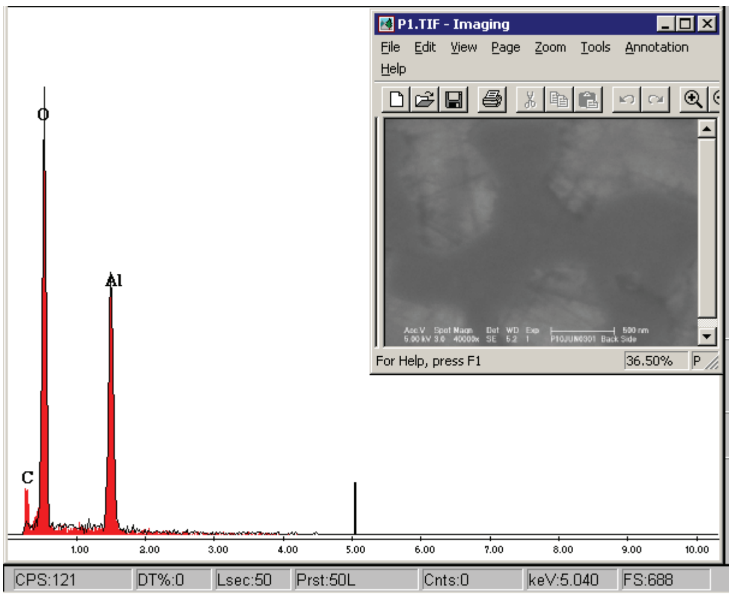

Fig. 7. EDX analysis to identify the contamination

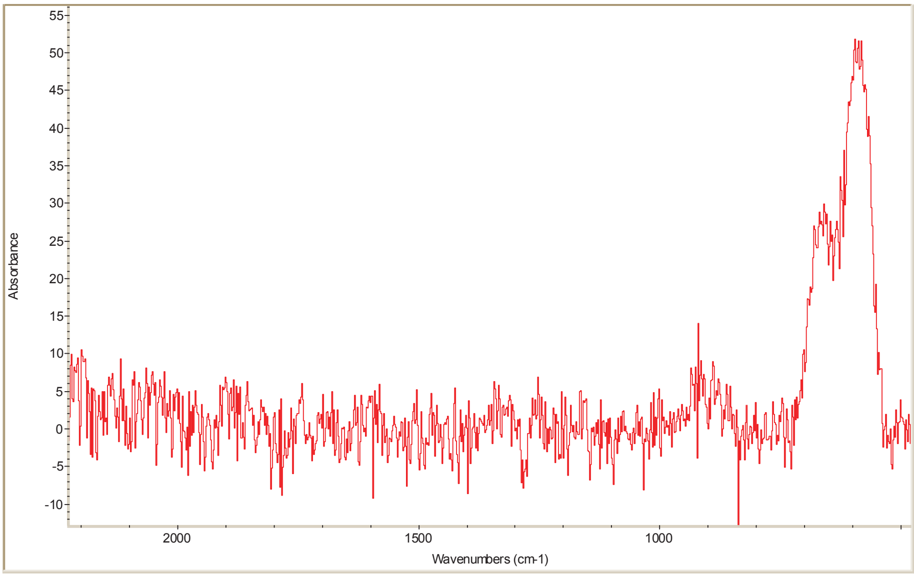

Fig. 8. Raman analysis spectrum for thin stain on the slider surface

From EDX analysis, it can be observed that the peaks on AFM image belong to alumina surface. This indicates that the alumina surface can be damaged easily by ultrasonics and solvent.

3.1.2. Raman analysis

The defective parts were also submitted for Raman analysis. The results obtained from Raman analysis is shown in Fig. 8. The stain on the slider surface can not be detected by Raman analysis.

3.2. Effect of ultrasonic power on parts damage with constant frequency and time

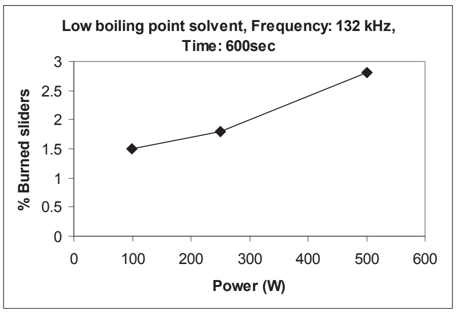

Fig. 9. Effect of ultrasonic power on parts damage

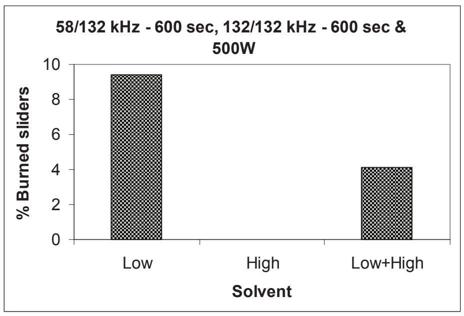

Fig. 10. Effect of cleaning solvent on parts damage

The impact of ultrasonic power on burned/eroded AlTiC surface is shown in Fig.9. From Fig. 9, it can be observed that as the ultrasonic power increases, the percentage contribution of eroded parts also increases. The darkening/erosion mostly occur at the contact area between AlTiC surface and tray used to hold the parts. The Ultrasonic Power delivered to the cleaning tank must be adequate to cavitate the entire volume of liquid with the workload in place. As tank volume is increased, the number of watts per gallon required to achieve the required performance is reduced. Cleaning parts that are very massive or that have a high ratio of surface to mass may require additional ultrasonic power. This excessive power may cause cavitation erosion or "burning" on soft metal parts (John Fuchs). The cavitation intensity is high for higher power levels as compared to lower power levels [Vetrimurugan et al., 2008]. Hence, the energy released during collapse, is higher for higher power levels. At high energy, mechanical vibrations can very easily be converted to heat, either by friction at interfaces between different parts or by damping ("internal friction") within the materials. This may be one of the reasons for darkening/erosion of the parts.

3.3. Effect of cleaning solvent on parts damage

The selection of cleaning solvent, cleaning time, U/S frequency and fixture material is the important factors to be considered to avoid parts erosion/darkening as well as to reduce surface contamination. Fig. 10 shows the effect of cleaning solvent on parts damage. The parts damage is more for low boiling point solvent (50^{o}C) as compared to high boiling point solvent (200^{o}C). Parts can also be damaged by the misapplication of cleaning fluids for a particular application. This result indicates that the aluminum in AlTiC surface undergoes darkening or oxidation when we apply U/S with low boiling point solvent. So, the aluminum surface requires the use of cleaning fluids which are specifically formulated for this metal to prevent darkening or oxidation of the surface. In case of Co-solvent mode (low + high), the damage is reduced as compared to low boiling point solvent (single mode). Co-solvent cleaning is inherently flexible and easy to operate, and a variety of low volatility, high solvency organic solvents are available for use in a co-solvent process. These processes allow us to vary the boiling point of the vapor degreaser as the situation requires, and the environmental and safety profile of the process is similar to the neat or azeotropic cleaning process.

3.4. Effect of U/S frequency on parts damage

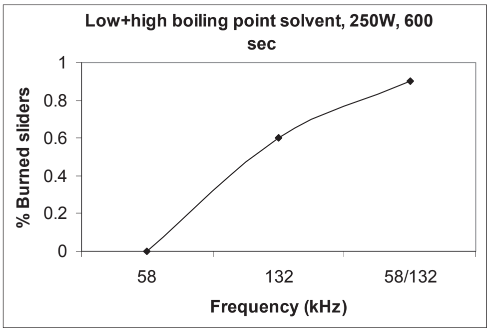

Fig. 11. Effect of ultrasonic frequency on parts damage

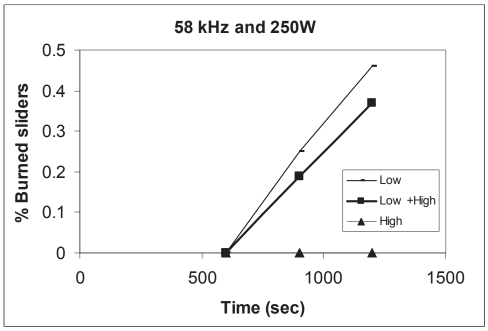

Fig. 12. Effect of sonication time on parts damage

Fig. 11 shows the effect of ultrasonic frequency on parts damage for Co-solvent mode. As the frequency increases the parts damage also increases. For higher frequency operation acoustic streaming velocity is the dominant mechanism (time independent fluid motion); (Vetrimurugan et al) which causes parts vibration and leads to more erosion/darkening at the contact area. For lower frequency (high intensity), cavitation is the dominant mechanism. Dual frequency operation (mode that combines a cavitational frequency with a streaming frequency) yields more damage than other modes of operation. This is due to the fact that for dual frequency operation (58/132 kHz), both cavitation and acoustic streaming are present whereas for lower frequency, only cavitation is present. In case of dual frequency operation, the input power drive to operate the

system was 1000 W as compared to 500W for single frequency operation. This may be another important reason for more parts damage in case of dual frequency operation compared to single frequency operation. At higher frequencies (132 kHz), the acoustic streaming velocity causes vertical motion of cleaning fluid which leads to more parts damage.

3.5. Effect of sonication time on parts damage

Ultrasonic cleaning time is another important parameter which affects removal of contamination and also parts damage. Fig. 12 shows the effect of sonication time on parts damage for 58 kHz with 250 W U/S power. It can be seen that until 500 sec there was no impact on parts damage for all kind of solvents used. After 500 sec, the surface damage increases with increase of sonication time for both low boiling point solvent and Co-solvent. The result also indicates that there is no damage for high boiling point solvent. One of the possible reasons is that the measured cavitation intensity is almost 1.5 times higher for low boiling point solvent compared to high boiling point solvent. Another possible reason is that the surface tension is almost two times higher for high boiling point solvent as compared to low boiling point solvent. Higher cavitation intensity gives more violent implosion of bubbles on the surface thereby leads to more parts damage.

3.6. Prevention of parts damage

Fig. 13 shows the effect of solvent cleaning on contamination removal for 58 kHz with 250 W and 600 sec sonication time. This condition gives no parts damage and also gives higher removal efficiency. The removal efficiency is high for Co-solvent, low for high boiling point solvent and intermediate for low boiling point solvent. The removal efficiency depends on many factors such as soil to be removed, type of soil, and type of contamination. From results, it can be observed that mixed solvent would be the effective way to improve cleaning efficiency and also reduce parts damage. Fig. 14 shows the effect of solvent on head/slider damage. From Fig. 14, it can be observed that the stain mark on the head is around 0.01% for the parts cleaned with acetone and almost 0% for the head cleaned with NMP and mixture of acetone and NMP. The shorter cleaning time with multiple frequencies can minimize or avoid the head/slider damage. For this condition, the removal efficiency was measured. The results obtained are shown in Fig. 15. Fig.15 shows the effect of solvent on contamination removal for the best cleaning condition developed. The best cleaning condition is 40 kHz with 5min, 58 kHz 5min, 132 kHz with 4min and 58/132 kHz with 4 min. The removal efficiency is high for multiple frequencies compared to single frequency (58 kHz). One of the best ways to avoid or minimize the burn mark/stain induced by ultrasonic is using of multiple frequency with shorter cleaning time and fix the hard disk drive head firmly on the fixture. The more vibration of the parts leads to more surface damage at the contact area.

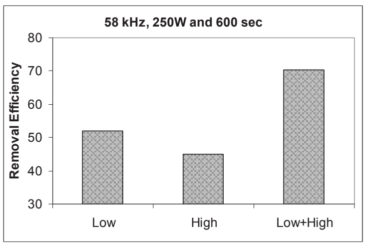

Fig. 13. Effect of solvent on contamination removal

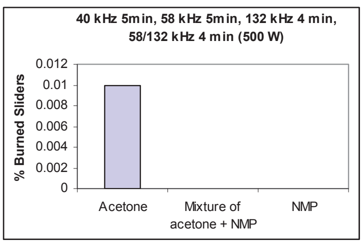

Fig. 14. Effect of solvent on head/slider damage

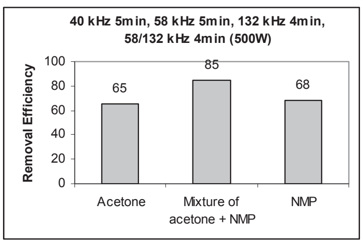

Fig. 15. Effect of solvent on contamination removal

4. Conclusions

The selection of frequency, power, cleaning time and cleaning solvent is crucial factors to prevent burn mark/stain like contamination on the slider bar surface. The use of Co-solvent mode can improve removal efficiency as well as minimize parts damage. In addition, parts are typically oscillated, either continuously or intermittently, to scan the object past areas of intense ultrasonic activity rather than allowing the parts to remain stationary. By moving the object, a more evenly distributed cleaning effect is produced which can completely prevent damage to sensitive devices in most cases. The parts damage is more for acetone as compared to NMP. The best cleaning condition is 40 kHz with 5min, 58 kHz 5min, 132 kHz with 4min and 58/132 kHz with 4 min. The removal efficiency is high for multiple frequencies compared to single frequency (58 kHz). One of the best ways to avoid or minimize the burn mark/stain induced by ultrasonic is using of multiple frequency with shorter cleaning time and fix the hard disk drive head firmly on the fixture. Parts can also be damaged by the misapplication of cleaning fluids for a particular application. The result indicates that the aluminum in AlTiC surface undergoes darkening or oxidation. The surface roughness (Ra) value obtained from AFM analysis for good surface and burned surface is 2.294 nm and 8.288 nm respectively. The Ra value is almost 4 times higher for burned surface. The experimental data indicates that the parts damage is more at the contact area between the AlTiC surface of the bar and tray used to hold parts. This is due to the fact that the stress amplitude is maximum at the fluid-solid interface because of reflection of the waves.

There are many factors affecting parts damage including frequency, power, and type of solvent. It also includes temperature, surface tension, viscosity, and density of the solvent. The selection of sonication time depends mainly on all the above factors. In order to achieve higher removal efficiency, the above factors should be considered. The cleaning operation will be completed with maximum efficiency only if the chemistry has a specific affinity for the soil. If it does not, even the addition of ultrasonics which usually enhances cleaning effectiveness while reducing chemical concentration, temperature, and process time will not achieve sufficient cleaning. The condition for removing the contamination cannot be reached based on one factor alone. Several interrelated factors must be considered to derive the most efficient, effective, and environmentally sound cleaning method. A through study of the particular cleaning problem with consideration of all the above consequences should be performed before choosing the systems to eliminate parts damage.

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